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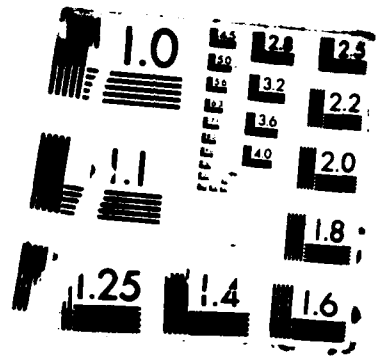(ENGLAND) J WILLIAMS 28 MAY 87 ONRL-7-010-C

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The International Symposium on Microwave
Signatures and Remote Sensing

Jerome Williams

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Held in January 1987 at Gothenburg, Sweden, this symposium was attended by participants from 16 countries. Discussions covered signatures from snow and ice, solid ground, ocean surfaces, and vegetation and considered systems and radar altimetry, interactions and modeling, and new methods. Keywords

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CONTENTS

THE INTERNATIONAL SYMPOSIUM ON MICROWAVE SIGNATURES AND REMOTE SENSING

1 INTRODUCTION

Ninety participants from 16 countries attended the Fourth International Symposium on Microwave Signatures in Remote Sensing held at the Chalmers University of Technology at Gothenburg, Sweden, from 19 through 22 January 1987. The symposium was organized by the Swedish National Committee of the International Union of Radio Science (URSI) and was jointly sponsored by URSI, the Swedish Board for Space Activity, the Swedish Defense Research Institute, and Chalmers University of Technology. This symposium was the fourth in a series of meetings, the other three being held at Berne, Switzerland, in 1974; Lawrence, Kansas, in 1981; and Toulouse, France, in 1984. Selected papers from this symposium will appear in a special issue of the *International Journal of Remote Sensing* sometime late in 1987. Prior to that, abstracts of all papers are available from Professor Jan Askne, Department of Radio and Space Science, Chalmers University of Technology, S-41296 Gothenburg, Sweden, for the amount of SKr200 ($34.00).

2 RADAR SYSTEMS

The conference was opened by Guy Duchossois of the European Space Agency, in which he described the ERS-1 satellite. The satellite has been supported in its development and production by 10 European Satellite Association (ESA) countries, plus Austria, Norway, and Canada. It is scheduled to be launched sometime between December 1989 and early 1990 with a scheduled lifetime of between 2 and 3 years. The sensors carried will include active and passive microwave and some passive IR for sea-surface temperature and atmospheric correction parameters. In addition, there will be a precise positioning sensor. The data analysis net that is planned will deliver some products essentially in real time (within 3 hours of reception), including: sea state, wind field, and wave spectra. In general, ERS-1 is a proof of concept experimental mission to prepare for a later, fully operational global system, which will be the European contribution to a worldwide oceanic monitoring system.

Two radars will be flown: one, a synthetic aperture radar (SAR) at 5300 MHz which can be used either as a wind scatterometer or in the image mode; and the other a KU-band radar altimeter. In addition, an along-track scanning radiometer (ATSR) consisting of a two-frequency microwave sounder will be used along with an IR sensor for temperature measurements and measurements of water vapor content of the atmosphere. The satellite will also contain some passive laser corner retro-reflectors, so that positioning from the ground can be accomplished in an accurate manner. The nominal satellite altitude is expected to be about 785 km with a sun-synchronized orbit having a mean nodal period of about 6028 seconds. The orbits are designed for a 3-day repeat cycle with a mean inclination of 90.5°. Since the active sensors take so much power, the duty cycle will be relatively short (i.e., the SAR duty cycle is figured to be about 10 minutes per orbit, with turn-on times selectable from the ground).

The areas of interest to the world community are probably reflected by the types of research proposals that ESA has received. To date, they have received approximately 220 proposals from 14 European countries, US, Canada, India, Japan, Australia, New Zealand, South Africa, and four international organizations. Sixty percent of these proposals were concerned with SAR data interpretation, while only 40 percent were concerned with the other sensors. About 20 percent of those interested in SAR data were interested in ice measurements.

Duchossois finished his presentation with a very disturbing table, reproduced below. It lists the remote sensing satellites with an oceanic orientation that are scheduled to be launched in the next 10 years or so. Note that of these satellites to be launched, only one that has a firm commitment, TOPEX, has any US involvement and that is only a partial one

Satellite	Country	Launch Date
MOS-1	Japan	1987
ERS-1	ESA	1989/90
POSEIDON	France	1990/91
TOPEX	US/France	1991/92
Radarsat	Canada/UK	1993/94
NROSS	US	??

in cooperation with France. If NROSS is not reinstated there are no US ocean-oriented satellites planned for launch at this time.

D. Massonnet of the French space agency (CNES) described the Varan airborne synthetic aperture radar which is under development by CNES at this time. It was first flown in February 1986, and modifications are proceeding as a result of that flight. The next flight was scheduled for March 1987; Massonnet indicated that so far their experience with the unit has been very promising. The hardware consists of a coherent pulsed radar with a frequency of 9.3 GHz, working at a pulse repetition frequency of either 400 or 800 Hz. The unit is designed to cancel pitch and roll of the aircraft and also take advantage of polarization information in the signal. Using the present minicomputer available, it appears that a single scene can be preprocessed in a time interval of between 1 and 2 hours.

S. Wall and J. Curlander (Jet Propulsion Laboratory, Pasadena) described the results of their procedure for some relative calibration of multiangle spaceborne imaging radar data taken from the 1984 SIR-B shuttle flight. They used lava areas in Hawaii and vegetation areas in Peru as reference patches for standardization. They are looking forward to the flight of SIR-C, which will happen, hopefully, sometime between 1991 and 1993, depending upon shuttle availability. In any event, they say the radar will be ready.

R.K. Moore described the development of a coherent antarctic radar depth sounder (CARDS) by his group at the Radar Systems and Remote Sensing Laboratory at the University of Kansas, Lawrence. This system was initially tested at the South Pole in December 1986. In order to measure ice thickness to a resolution of ±5 meters, they are using a 16-ns pulse and a 17-MHz bandwidth, while to keep the size of the system small they chose a frequency of 150 MHz. When the system is flown from a C-130 aircraft the range is mainly governed by transmitted power since losses of EM energy within the ice at a frequency of 150 MHz are very large. The CARDS group have also used this equipment in preliminary runs on a sled, rather than flying it from an aircraft. After the flights in December of 1986, it was apparent that the system still needs more work, and future plans include the addition of software to utilize polarization information.

N. Skou, Technical University of Denmark, Lingby, described a very accurate C-band noise scatterometer-radiometer system. This is a C-band noise injection radiometer developed at the university some years ago, and since it has performed extremely well over a large number of field experiments, the instrument has been modified to serve as a combined radiometer and scatterometer. The developers expect that precise simultaneous measurements of brightness, temperature, and backscatter coefficients will thus be obtained. It appears that the accuracy of measurements is to the first order, solely dependent on the accuracy with which the antenna illumination integral can be evaluated.

Radar altimetry over inland water was described by C. Rapley and his group from the Mullard Space Science Laboratory, University College London, UK. This group has worked with SEASAT data for some time now as part of a preliminary investigation for development of ERS-1 hardware. They looked at the shape of returned pulses over different kinds

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of terrain, and selected examples that had relatively simple wave forms. They then related these wave forms to the relative roughness of various areas in an attempt to develop some sort of calibration or interpretation technique for the data that will come from ERS-1. It appears that using the techniques developed, water levels can be obtained to an accuracy of about ±0.5 meters.

D. Wingham from the same laboratory, has looked at SEASAT data with respect to return signals from ice. The ice return signal compared to that from water has a narrower pulse width and higher intensity, and Wingham appears to have devised a scheme to separate the coherent and the incoherent portions of the signal. However, he does not think that altimeter measurements can provide a measure of ice distribution. One problem concerns the fact that there is no ground truth for the SEASAT data, so there is no information regarding the presence or absence of puddles on the ice. Hopefully, ERS-1 will collect altimeter data over land and ice areas so that the signals can be related to ground truth. Wingham also indicated that passive microwave measurements of ice concentration are not very good either.

3 OCEAN SENSING

W. Alpers (University of Bremen, West Germany) started this session with a tutorial paper on microwave remote sensing of the ocean. He described in some detail, from a reasonably elementary point of view, the whys and wherefors of using microwave sensors to measure oceanic parameters. Microwave sensors are weather independent so the radar altimeter, wind scatterometer, and synthetic aperture radar have all been used. In relating the returned radar signal to sea state it has been found that the scattering cross section appears to increase linearly with the sea state for wind speeds up to approximately 27 meters per second. Reliable data for wind speeds above this value are not available at this time.

One of the present areas of active ONR research support has to do with or-

ganic films occurring naturally over the world ocean surface. Alpers indicated that it does not seem possible to separate these organic films from petroleum spills by means of radar backscatter data alone. He presented some interesting data indicating that an oil patch of about 750 meters in extent will damp waves 3 meters high by 10 to 15 percent. This was an interesting statement since previously it had been thought that the capillary waves were dampened by oil spills but not gravity waves of this size.

G. Valenzuela (Naval Research Laboratory, Washington) described the work that he, D. Sheres, and D. Chen have been doing on remote sensing of wave patterns with oceanographic implications. They had looked at the effect of currents on ocean surface waves and found that in deep water, currents tend to focus and defocus wave energy. In shallow water, depth variations also cause wave refraction as well as modulation of the surface velocity distribution of long waves, which adds to the refractive effect. Thus, the wave field in shallow water is affected directly by bottom topography and indirectly by the nonuniform surface currents perturbed by the bottom changes. It is this effect which he thinks contributes to the ability of SAR images to sometimes accurately reflect bottom topography.

R. Moore in conjunction with R. Lawner, J. Nice, and A. Chaudhry (all from the University of Kansas, Lawrence) described some measurements taken from tower-based radar backscattering systems that showed a number of "sea spikes" resulting from ocean waves. These sea spikes are sudden jumps in the intensity of the return signal inconsistent with various mathematical models. The group studied these spikes in an attempt to determine their origin because identification of the origin might be useful in separating the backscattered power explained by Bragg resonance from that caused by other processes. Moore and coworkers found that the spikes appear to be associated with breaking wave foam, steep slope, concave surface deformation,

and wedge diffraction. Their solution was to use data analysis techniques to rid the data of these spikes.

A. Harbitz (University of Tromso, Norway) also studied these sea spikes. He, however, looked at the spike-producing sea surface using a video camera and measuring the intensity of each pixel in the visible scene in order to get the wave spectrum and wave height measurements. It is also possible to work backwards and create simulated photos, when given a particular wave spectrum. As a result of this study, he felt that optical techniques may be a more efficient tool than radar for the determination of ocean wave spectra.

Another investigator from the University of Tromso, T. Eltoft, performed a statistical study of sea spikes using multifrequency CW radar. He did this by looking at the coherence between different radar return signals at different frequencies. The calculations of the correlations and the cross correlation functions of these two signals yielded a good signature of the sea spikes and may also provide some information on the generation mechanism of this phenomenon.

R. Gairola, B. Gohil, and P. Pandey (Space Application Center, India) described a study of the dependence of specular microwave sea scatter and slope distribution on wind speed. They were particularly interested in the nature of the return signal as affected by the production of white caps. They found that the radar reflectivity drops rapidly to values below 0.1 as the thickness of the foam increases above about 1 mm. On the basis of their reflectivity data they were able to develop a model which agrees quite well with the empirical results, except in regions where white caps are just starting to form.

R. Glazman (Jet Propulsion Laboratory) described a study using SEASAT scatterometer measurements in an attempt to determine a relationship between sea-surface parameters and the wind fetch. He found that with higher fetches the apparent scatterometer wind (the wind measured by the radar scatterometry) decreases as the actual wind increases. Ap-parently this results from non-Gaussian sea surfaces being produced in regions of higher fetch. Consequently, in high-fetch regions the scatterometry wind values appear too high. This can be explained by assuming that as the fetch increases more and more of the wind energy is inputted at the high-frequency end of the spectrum. In actuality, this reference to wind fetch is really referring to the degree of departure of the actual wave field from the idealized, fully developed wave field, wherein the fully developed wave field is not only a function of fetch but also wind speed and duration.

Also looking at some SEASAT data, was B. Raigniac (Gerdsm, Le Brusc, France). He flew an X-band synthetic aperture radar from an aircraft and compared the returned signals for a given sea state with those available from SEASAT data. His data showed internal waves, ship wakes, oil slicks, and bathymetric features, in the same manner as the L-band SAR used by the SEASAT satellite. Although the images obtained with the X-band radar were not quite so dramatic as those with the SEASAT L-band, these experiments were of a qualitative nature, and clearly demonstrated that the potential for use of X-band aircraft SAR to visualize sea-surface phenomena previously observed by SEASAT already exists. The suggestion was made that experiments be developed to determine the differences in images produced by different frequency radars.

Describing some SAR images along the coast of Japan, S. Tanaka, T. Sugimura, and H. Kimura (Remote Sensing Technology Center, Japan) described some images received by SIR-B radar. They discussed a pattern closely associated with a lava formation in Mikawa Bay, central Japan. This same pattern cannot be duplicated by any visual imaging system. Other images seen at river mouths and along the shoreline consisted of bright and dark features and appeared to have some relation with underwater topography. The pattern along the shoreline may also indicate the interaction between waves and the sea bottom.

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T. Macklin and R. Cordey (Remote Sensing Group at Marconi Research Center, UK), also analyzed some SAR data of North Atlantic surface wave spectra obtained from SIR-B. They found that wave spectra produced from SAR data appears to lose the high frequencies and does not show as much energy for azimuth-traveling waves as for other directions. This is a marked limitation of SAR for use in determining the spectrum of ocean waves. Fortunately, most wave energy is contained within the lower frequencies, so that the total energy involved in this angular effect is relatively small, but under certain conditions it may be a significant amount.

A study by R. Kumar and A. Sarkar (Space Applications Center, India) was concerned with the effect of atmospheric absorption on the sensitivity of microwave-backscattering/surface-wind relationships. The physical principle behind the operation of radar scatterometry is that the strength of the radar return is proportional to the capillary wave amplitude, which in turn is proportional to the surface wind stress. The backscattered signal gets attenuated as it passes through the atmospheric column before it is sensed by the sensor aboard the satellite. For selection of the optimum scatterometry frequency, it is important to know the overall sensitivity of the backscattering coefficient to the surface wind. Kumar and Sarkar's measurements indicated that for wind speeds up to 10 m/s the frequency band region for maximum wind sensitivity for satellite scatterometry is between 13 and 18 GHz. For higher wind speed conditions, the sensitivity is reduced at all frequencies.

4 INTERACTION AND MODELING

A. Fung (University of Texas, Arlington) started the session on interaction and modeling with a paper on theoretical modeling of microwave scattering processes. This paper indicated some of the problems still remaining in theory development to support radar scattering data analysis. Surface scattering, which includes new smooth surfaces and new rough surfaces, along with volume scat-

tering, which usually is assumed to be represented by a rather dense medium, must both be modeled. Surface scattering can be solved exactly if the surface current can be obtained. Present models appear to be moving in the right direction, Fung said, but Bragg scattering values are probably the best single values available at present for surface scattering. There are two approaches in the volume scattering portion of the model; one is the intensity approach, which has to do with the near field, where it is assumed that there are inhomogenous layers of individual scatters, either spherical, disc, or needle. The other approach is the field approach, which assumes a coherent field. Presently, it is not clear which theory fits the real world best. Volume scattering in which a sparse medium is assumed is also possible, but no work is being done on sparse media at this time.

G. Kristensson (Royal Institute of Technology, Stockholm, Sweden) and R. Krueger (Ames Laboratory, Iowa State University) gave a presentation on direct and inverse scattering in the time domain for a dissipative wave equation. This paper was devoted to direct and inverse scattering of transient waves in inhomogeneous media. The medium was assumed to be stratified, so that variations in permitivity and conductivity occurred in the vertical direction only. Scattering and propagational operators were defined and equations which govern their behavior developed. It was shown that finite time traces of the scattering kernels sufficed to simultaneously determine the permitivity and conductivity of the profile.

Another theoretical paper, this one by G. Wanielik and D. Stock (AEG Research Institute, West Germany), was devoted to classification and cluster algorithms based on the features of the scattering matrix. Polarimetric radars are able to measure the scattering matrix of a reflecting object and, therefore, able to get the entire informational data set in the far field of the object. The scattering matrix is dependent on the chosen polarization basis, the transmitted frequency of the monochromatic radar signal,

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and on the line-of-sight radar reflection object. A mathematical model relating these parameters was developed but no data were shown.

The effective scattering of dry snow, wet snow, and sea ice was addressed theoretically by A. Sihvola and J. Kong (Massachusetts Institute of Technology, Cambridge). This was done by modeling the effective permitivity which can be calculated through a quasi-static analysis. This, however, restricts the result of this dielectric mixture theory to cases where the size of the inhomogeneities is much smaller than the wavelength. The theory can not only be applied to snow but also to the study of absorption attenuation due to clouds, fog, haze, hail, rain, snowfall, and dust storms. Dry snow is a two-component mixture consisting of air and ice. The mixture is generally dense but the dielectric constants of air and ice are comparable; therefore the different models predict fairly similar results for the effective permitivity of dry snow.

Wet snow is somewhat more complex since it can be considered either as a three-component mixture of air, ice, and water, or a two-component mixture of dry snow as the background and water particles as inclusions. These two approaches give slightly different results for perm'tivity of wet snow.

Sea ice is a three-component mixture with pure ice as background and air bubbles and brine pockets as inclusions. The brine pockets are prolate spheroids with a small axial ratio, and there is experimental evidence that they are oriented in a preferred direction. In this model it was assumed that they are not exactly aligned but rather have a Gaussian angle distribution about a preferred axis. Because the volume fractions of air and brine are fairly small, all self-consistency models predict comparable results. It was shown that the anisotropy is the largest in first-year ice, which also has the bigger overall effective permitivity, and smaller in multiyear ice, where the salinity is small. The difference is especially pronounced in the imaginary part of the permitivity.

A. Guissard and P. Sobieski (University of Louvain, Belgium) attempted to develop an approximate model for microwave brightness temperature of the ocean. They did develop a model for estimating the sea-surface perturbation on the microwave brightness by using a correction factor related to the ripple height, included the effect of the atmosphere and of ripple.

J. Lee (Syracuse University, New York) presented a theoretical model of ice scattering that accounted for the effects of absorption, volume scattering, anisotropy, and layering. He applied the model to the remote sensing of arctic sea ice, but left multiple scattering calculations related to passive remote sensing of sea ice as a task for the future.

Another sea-ice model was described by R. Johansson and J. Askne (Chalmers University, Sweden). They developed a model for the scattering from low-salinity ice in the Gulf of Bothnia. In this body of water there is only first-year ice which has a salinity of between 0.25 and 1.5 ppt because the salinity of the Gulf itself is less than 6 ppt. The ice thickness found is typically between 20 and 70 cm. With this low-salinity water as the source from which the ice is produced, the model indicates Gulf of Bothnia ice has properties which are quite different from the more common conditions for arctic first-year ice. Real data have not been applied to the model as yet, but from preliminary results it appears that further theoretical and experimental studies will be required.

5 NEW METHODS

D. Gjessing (Royal Norwegian Council for Scientific and Industrial Research) discussed the design of radar systems for optimizing return signals. He indicated that if it is desirable to enhance the signal from a particular target at the expense of the background, one should optimize the illuminator to four-dimensions--that is, three in space and one in time. This can be done by considering the scattering object to be characterized

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by a four-dimensional irregularity spectrum. This will require much more sophisticated data analysis components in future radars as use is made of pulse, chirp, or holographic concepts and targets are identified by comparison of the signal with specific elements of an extensive library.

Another type of radar system was described by E. Aarholt, also from the Royal Norwegian Council. He introduced the possibility of using multifrequency radars. In particular, a dual frequency version centered at 1.5 GHz has been designed for snow prospecting and it is now commercially available as a self-contained unit installed on a snow sledge for use with snow vehicles. The radar measures the distance to the ground by calculating the differential phase between two microwave carriers. Unambiguous snow depth measurements from 0.1 to 6 meters with an accuracy of ±2.5 cm have been made. A conventional real-time graphics microprocessor takes care of data logging and has data storage capacity for an entire day of continuous use at platform speeds of about 20 km per hour. Since the device works primarily on the reflection of the radar signals from an interface at which there is an impedance discontinuity, it appears that the same concept should work for snow-ice and ice-water interfaces.

J. Hjelmstad, also of the Royal Norwegian Council, described some of the effects produced by the sea surface on the use of communication and radar. He characterizes the sea surface in terms of a directional wave number spectrum and a velocity distribution associated with each wave number component. These parameters can help in describing various mechanisms such as shadowing effects, varying dynamic stability, capillary waves, production of foam, breaking waves, large amounts of aerosol produced by breaking, and precipitation chops in the sea surface. Using this model in conjunction with some actual measurements, Hjelmstad was able to show that communication and radar losses could be modeled in terms of sea-surface signatures.

P. Gudmandsen and N. Skou (RS Consultants, Denmark) discussed a study of a microwave radiometer for possible placement aboard the Columbus portion of the proposed polar platform of the European space station. This multichannel imaging microwave radiometer (MIMR) is a six-frequency system with a 4-meter rotating offset parabolic reflector antenna which would perform a conical scan of the earth's surface. Its frequencies would range from 6.84 GHz to 90 GHz so that the spatial resolution would vary from about 20 km to 2 km within a swath of 1350 km when the platform is at an altitude of 850 km. As conceived, the instrument is very large with appreciable mass and, therefore, has serious implications on the design of the satellite. In particular, the large rotating antenna may provide severe torque problems which may force a reduced version of the design.

A new method of using radar frequencies in remote sensing applications in order to achieve greater penetration of the target was described by H. Hellsten and S. Odman (National Defense Research Institute, Sweden). This system is the Coherent All Radio Band Sensing (CARABAS), which is essentially a low-frequency SAR. The SAR image is limited by a particular form of noise, called speckle, which may be described as variations of refectivity between neighboring imaging elements (pixels) which do not uniquely correspond to real variations in the character of the target surface. Reliable information can be derived from SAR images only by statistical analysis of the reflectivity distribution over a large number of pixels.

CARABAS is an attempt to realize a low-frequency, large relative bandwidth SAR, where the large relative bandwidth results in a high degree of measurement data uniqueness (minimum speckle). Such a SAR demands an extremely large synthetic aperture and signal processing routines different from those used in conventional microwave SAR. In this paper the authors described some of the hardware and operational considerations, along with some of the data analysis techniques, for a useable CARABAS system.

6 SENSING SNOW AND ICE

This session was begun by R. Moore (University of Kansas) in a tutorial review of radar experiments in monitoring and measuring sea ice. Moore discussed two types of radar: synthetic aperture radar (SAR) and real aperture radar (RAR). He indicated that the low penetration of the microwaves in first-year ice is primarily due to the relatively high ice salinity. Therefore, as the ice ages higher penetration can be expected since the brine pockets in the ice are replaced with air pockets. Radar penetration is also very low when the ice surface is covered with water, as occurs in spring and summer. During the winter time, it is possible to determine ice type by using intensity variations in the radar return, since no melt water is present at this time of the year. Moore indicated that our knowledge of sea-ice scattering is now great enough to permit the first steps to automated analysis, but significant research needs to be done into the phenomenology of autumn ice, thinner types of ice, and ridges. Moreover, research is needed to verify experimentally the current theories and provide information allowing improved theories to be developed.

In the discussion that followed, T. Shutko (Academy of Sciences, Moscow) indicated that RAR data has been used in the arctic by USSR helicopters to locate leads necessary in releasing vessels from ice entrapment. He also indicated that radiometers can be used to determine ice or no-ice conditions but the resolution is very poor.

The dielectric properties of freshwater ice were measured by C. Matzler and U. Wegmuller (University of Berne, Switzerland). Using microwave frequencies they measured the dielectric constant at temperatures between 0 and $-30°C$ using frequencies between 2.4 and 94 GHz. The results showed a slight increase of the dielectric constant with increasing temperature from a value of 3.16 at $-30°C$ to 3.19 at $-0.5°C$. They also show a marked increase in the imaginary part of the dielectric constant from 0.0002 at a frequency of 2.4 GHz to about 0.009 at a frequency of 94 GHz. These values of the imaginary part of the dielectric constant are also related to the purity of the ice, with lower values at the same temperature and frequency being found for ice made from distilled water.

B. Reber, C. Matzler, and E. Schanda (University of Berne, Switzerland) presented some data taken in support of an effort to model microwave scattering from refrozen snow crusts. The scattering was calculated on the basis of snow structure analysis and the first-order Born approximation for different crusts. Good correspondence with microwave measurements was found except when the scattering model assumed the snow grains to be spherical in shape.

L. Fedor (NOAA, Boulder), E. Walsh, and D. Cavalieri (NASA, Goddard) reported on a study of the flow characteristics and surface topography of an Arctic ice pack. Data were taken in 1984 from a P-3 aircraft participating in the NOAA Arctic Cyclone experiment. During the course of that experiment data were taken over the sea ice off the coast of Greenland using a surface contour radar (SCRN). This is a 36-GHz scanning pencil-beam radar which produces topographic and backscattered power maps having high spatial resolution (3 m by 5 m). Analysis of 35-mm color photographs taken coincidentally with the radar data provided documentation of the mesoscale features of the ice cover in the region. The radar backscattered power sharply delineates individual ice floes when they have a smooth appearance in the photography, and they stand out as uniformly bright objects in the radar return. The elevation data is less impressive but still consistent with ice surface elevation as determined from an analysis of aerial photography. However, it is still not clear whether the radar images are of snow or ice surfaces.

The possible use of radar for measuring frazile in water was discussed by M. Toikka (Helsinki University of Technology, Finland). In cold turbulent water ice present in the form of fine suspended crystals is known as frazile. It can greatly affect the characteristics of

river flow and can also adhere to underwater objects to form anchor ice. In both cases conveyance capacity of a water course can be reduced substantially. When frazile adheres to submerged water intake structures it can partly or completely block off the water intake and cause problems such as coolant water supply for power production. Frazile can also block a whole river and cause severe flood damage. For these reasons the Union of Finish Power Plants funded a study to determine the characteristics of frazile forming and the effects to the conveyance capacity of a water course. The radars of the radio laboratories of Helsinki University of Technology were used to measure frazile ice in the rivers. It appears that this radar mechanism may be the only method of detection available at this time. To detect frazile under an ice cover, they used short pulse radar—a modification of a subsurface interface radar to which a new signal processor and video display systems has been added. The operating frequency was 120 MHz, which corresponds to a wavelength of 2.5 m in air, 0.27 m in water, and 1.4 m in solid ice. The antenna and a sledge were towed with a snowmobile, and the measured profile was recorded on magnetic tape. Results indicate that this methodology of monitoring frazile is extemely effective, and it was able to pin-point regions of the water column where frazile existed.

H. Skriver (Technical University of Denmark) described techniques utilized in estimation of sea-ice parameters from SAR data. The work concentrated on two sea-ice parameters: ice type and ice movement. The ice type determination was based on a pixel-by-pixel classification scheme including speckle reduction. This simple approach was surprisingly gocd and was also used for a rough estimate of ice concentration. The automatic determination of ice motion is based on delineation and reidentification of floes in two or more consecutive scenes. A segmentation method using an edge-detected image has been investigated to perform floe delineation. Shape parameters and parameters of the inner structure of floes have been used for the floe characteriza-

tion essential for floe reidentification. The influence on the algorithms of speckle inherent to SAR data was studied, and various speckle reduction techniques were investigated.

A comparison of SEASAT radar altimeter and SAR data over sea ice was described by L. Ulander (Chalmers University of Technology, Sweden). The radar altimeter on SEASAT demonstrated the possibility of obtaining precise measurements of ocean topography, marine geod, wave heights, and sea-surface wind speeds. Despite not being designed for operation over sea ice it produced large quantities of data over such regions. It has been suggested that several sea-ice parameters, such as ice type, ice concentration, freeboard, and surface roughness could be obtained from the radar altimeter data. Ulander reported on a comparison between radar altimeter and synthetic aperture radar data in an effort to provide "ground truth" for the interpretation of radar altimeter data over sea ice. Unfortunately, examination of the SAR altimeter sensor geometry implies that there were no spatial and temporal coincident data, so the requirement of temporal coincidence was relaxed in order to permit the comparison of the two data sets. When this was done there was some relation especially at the edges of ice sheets, indicating that SAR or the altimeter might be used for the determination of ice boundaries.

During the marginal ice zone experiment (MIZEX) in 1983 and 1984 a number of different remote sensors were utilized in the arctic region to determine ice characteristics. An analysis of these data was reported by R. Shuchman and B. Burns of the Environmental Research Institute of Michigan (ERIM). An extensive field program in the region of the outermost edge of the polar ice field was conducted in the Fram Strait region of the Greenland Sea using SAR, side-looking airborne radar (SLAR), passive microwave imagers (PMI), radar altimeters, and aerial photography. The aircraft flying the sensors was flown so that coincident coverage of the ground-truthed sea ice and ocean areas occurred. At the same time,

satellite data were taken so that a comparison of satellite and aircraft data was possible. Ice concentration estimates derived from SAR data were compared to those obtained from passive microwave imagery at several frequencies. The comparison was carried out not only to evaluate SAR performance against the more established microwave techniques but also to investigate the causes of discrepancy in terms of how ice surface conditions, imaging geometry, and choice of algorithm parameter affects each sensor. Active and passive estimates of ice concentration for these data both agree to within ±12 percent on the average.

7 CONCLUSIONS

Although microwave signatures and data have been studied for some time, it was obvious from this conference that a great deal of work still remains to be done if the existing data sets are to be adequately understood. Especially in the region of ice and snow, the data are very inconclusive and the theoretical background to interpret these data is not as sophisticated and polished as one might hope. Thus, the conference showed not only how far we have come but also how far we still have to go. It is obvious to me that if the ERS-1 data are to be interpreted intelligently much more research in microwave signatures will be required. Hopefully, this work will continue in the time remaining between now and when ERS-1 is flown.

Although there was a relatively small group of scientists at this meeting, the number of countries represented was quite large and it appeared to me that the major constituents of the microwave signature community were, if not all present, well represented. The relatively small size of the meeting tended to aid in promoting discussion, and the program was so arranged that there was ample opportunity for such discussion. In addition, many of the participants were housed in the dormitory of the University so that there was lots of "shop" talk during the off hours.

From the comments of the various participants, and the nature of the discussions that I heard, my conclusion would be that this was a very sucessful conference and probably would influence future research significantly.

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